DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

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A NEW OCCURRENCE OF MAFIC IGNEOUS ROCKS BENEATH THE NORTHERN MURRAY BASIN

GEOLOGICAL SURVEY

by

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F RADKE

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by W. V. Preiss and F. Radke

ABSTRACT

Nanyah 1 borehole, drilled as a hydrogeological observation bore in the northern Murray Basin, was extended to basement to intersect a prominent aeromagnetic anomaly. A 3 m bottom-hole core of mafic igneous rock was taken at 412 m. The upper 1.6 m of core is basalt, separated from an underlying coarse-grained dolerite by a 45^{o}-dipping sharp contact. Textural relationships suggest that the dolerite is the older; it is either overlain by or, more probably, intruded by the basalt. A thin basalt vein intrudes the dolerite lower in the core. The mafic rocks, which show no evidence of penetrative deformation, contain plagioclase and pyroxene with minor amphibole, potash feldspar and opaques, including magnetite; alteration products include chlorite, prehnite, sericite or clay, calcite and zeolite.

Although major and trace element geochemistry of the mafic rocks does not closely match that of other known igneous suites in South Australia, a number of geochemical plots suggest an affinity with the early Palaeozoic Kulyong Volcanics. The dolerite plots within the calc-alkaline field on a Pearce and Cann triangular diagram (Ti/100 - Zr - 3 Y), while the basalt falls on the boundary between intraplate and ocean-floor basalts.

INTRODUCTION

The pre-Permian geology of the Murray Basin region is still poorly understood because drillholes with good basement intersections are rare and widely scattered, yet this region holds the key to understanding the tectonic setting of the Adelaide Geosyncline and its relationship to the Palaeozoic mobile belts of eastern Australia. In addition, the mineral potential of the basement to the Murray Basin has yet to be adequately assessed. Limited outcrop and drillhole data indicate that igneous rocks occur at several localities, while the patterns of aeromagnetic anomalies suggest that such occurrences may be extensive, and further exploration is warranted.

The basement geology of the Murray Basin region has been variously portrayed on published geological maps. On RENMARK, Firman (1971) indicated extensive Kanmantoo Group beneath the Permian to Cainozoic sediments of the Murray Basin, and indeed the schistose metasandstones cored in wells such as Loxton No 2 do resemble some facies of the Kanmantoo Group. On the other hand, the tectonic sketch for CHOWILLA (Rogers, 1978) shows the northern part of the basin as underlain mainly by Adelaidean rocks. Drillholes such as Oakvale 1 (Forbes, 1983) entered grey, laminated silty shale of very low metamorphic grade that is consistent with lithologies seen in much of the outcropping Adelaidean sequence of the Nackara Arc west of the Murray Basin. A number of recent water and coal exploration bores have intersected various mafic to acid igneous rocks, but mostly only cuttings are available for these.

In the Coonalpyn-Yumali area, CSR Ltd intersected extensive mafic volcanic sequences in drillholes centred on large aeromagnetic anomalies (Gidley, 1983, Tonkin et al., 1986). Other igneous rocks include the outcropping post-tectonic Black Hill Norite and unfoliated granitoids at Murray Bridge, Mannum and Long Ridge, as well as subsurface granite near "Kia Ora". Brown et al. (1988) have made a regional aeromagnetic interpretation of the basement to the Murray Basin in South Australia, Victoria and New South Wales. In Victoria, the Stavely Belt of mafic to intermediate volcanics (Buckland, 1987) crops out between the Grampians and Stawell, but has been inferred from aeromagnetic anomalies to extend in a northwesterly direction towards the South Australian border, (near Peebinga) where the anomalies are abruptly terminated.

A series of strong arcuate aeromagnetic anomalies parallels the trends of Delamerian fold axes in the Nackara Arc to the west. One of these was explored by CRA Exploration Pty Ltd (Lewis, 1985) who intersected severely altered volcanics in one drillhole in the "Pine Valley" area. Another anomaly occurring to the southeast of the Pine Valley anomaly forms the subject of this investigation.

The locality diagram Figure 1 has been compiled from various sources to indicate some of the broad areas of different rock types intersected in drillholes.

STRATIGRAPHIC DRILLING - NANYAH 1.

Nanyah 1 borehole was drilled vertically through Tertiary and Cretaceous strata north of Renmark as part of a network of observation wells to monitor the pressure and salinity of the Renmark Group confined aquifers in the Murray Basin (S. R. Barnett, pers. comm., 1988). Nanyah 1 (grid reference 448200 mE, 6289100 mN) was sited by WVP 25 km west of "Canopus" in order to intersect the southern termination of an aeromagnetic anomaly 30 km long, in an area where previous information on basement geology was totally lacking. Drilling was therefore extended below the aquifers into basement. Weathered basement (green clay) was intersected at 374 m. A weathering profile about 20 m thick was penetrated and rotary drilling was continued in fresh bedrock to 412 m. A 3 m length of HQ bottom-hole core was recovered from 412-415 m.

The upper section of this core consists of fine-grained, dark grey-green mafic igneous rock with feldspar laths and green ?chloritic blebs. At 413.6 m, there is a sharp contact, dipping at about 45^{o} to core axis, separating the fine-grained rock from an underlying coarse-grained, ophitic-textured rock with 1-3 mm feldspar laths. Examination of cuttings from above 412 m suggests that the overlying rock is mainly fine- to medium-grained basalt.

PETROGRAPHY

The following samples were taken from the drillcore and described by Radke (1989):

6930RS1: Fine-grained dolerite or basalt, 412.2 m.

6930RS2: Deformed and prehnite-veined dolerite or basalt, 412.6 m.

6930RS3: Altered fine-grained dolerite or basalt with veins, 413.0 m.

6930RS4: Contact of basalt and coarse-grained dolerite, 413.6 m.

6930RS5: Medium to coarse-grained dolerite, 413.8 m.

6930RS6: Basalt-veined dolerite, 414.3 m.

From the contact relationships, the lower coase-grained dolerite is interpreted as the older. Sample 6930RS5 is typical of this unit and consists of the following constituents:

	%
Plagioclase	45
Chlorite	25
Pyroxene	10
Amphibole	5
Potash feldspar	5
Quartz	3
Apatite	1
Epidote	Tr-1
Carbonate	Tr-1
Sericite/clay	Tr
Opaques (mainly magnetite)	5

Euhedral to subhedral plagioclase laths up to 3 mm long are intergrown with interstitial mafic minerals and smaller amounts of very fine feldspar laths. The plagioclase is quite fresh, showing only very localised incipient alteration to sericite or clay, but generally has a slightly turbid, reddish-brown colour. Laths are commonly slightly broken and deformed.

The interstitial mafics consist largely of chlorite intergrown with smaller amounts of potash feldspar and pyroxene. The pyroxene forms anhedral to subhedral crystals up to 1 mm in size, many of which show marginal replacement by a pleochroic brown amphibole. The chlorite forms small flakes less than 0.1 mm wide with a pleochroic green colour and low birefringence.

Potash feldspar is locally intergrown with the chlorite as small crystals, many of which have prismatic lath shapes. Locally quartz also forms anhedral grains intergrown with chlorite. Traces of epidote were noted locally as small grains and granular aggregates. Very thin, elongated apatite crystals are generally intergrown with the potash feldspar and chlorite. Traces of carbonate (mainly calcite) were noted locally as discontinuous patches or vein-like structures.

Opaques are disseminated through the rock as anhedral to subhedral grains up to 0.5 mm wide. Some of the crystals have elongate shapes and could represent disseminated ilmenite; others are sections of octahedra, suggesting magnetite. The hand specimen is quite strongly magnetic.

This is a mafic intrusive rock with a doleritic texture, which has been subjected to slight deformation and alteration. Potash feldspar, quartz and associated apatite tend to be concentrated in irregular patches intergrown with chlorite and are thought to be largely of metasomatic or deuteric origin.

Sample 6930RS6 is a similar dolerite, but is transected by a fine-grained basaltic vein 14 mm wide. In the dolerite, a minor mineral intergrown with chlorite may be amphibole, while interstitial patches of potash feldspar also have fine chlorite intergrowths. These areas are also believed to be of metasomatic or deuteric origin.

The vein consists largely of fine-grained basalt very similar to that in contact with dolerite at 413.6 m. A few small plagioclase laths are disseminated through a turbid brown matrix, and there are some large patches of granular quartz with localised prehnite intergrowths, with grain size 0.5-1.0 mm. Minor calcite with coarsely granular texture is locally concentrated along the margins of the basalt vein.

Minor amounts of finely divided sericite or clay are locally intergrown with the plagioclase as an incipient alteration product. Opaques, probably magnetite, are disseminated through the dolerite as anhedral to subhedral grains and aggregates up to 0.5 mm wide. Minor opaques also occur as fine intergrowths with the basaltic vein, but these are not strongly magnetic.

The fine-grained matrix of the basalt vein has been completely replaced by turbid brown material but still retains irregular textures suggestive of its originally vitreous character. Local patches of quartz and prehnite fill irregular voids within the basalt vein. Narrow marginal calcite veinlets are oriented parallel to the contact between the vein and host dolerite.

In sample 6930RS4, which spans the contact, the dolerite is sharply truncated by the overlying basalt.

Single plagioclase laths projecting from the dolerite can be seen to be broken off at the contact and fragments incorporated in the basalt. The dolerite is quite coarse-grained right up to the contact; plagioclase crystals up to 3 mm long are intergrown with interstitial pyroxene and chlorite and show incipient alteration to finely divided sericite or clay. The pyroxene forms anhedral to weakly subhedral crystals up to 1 mm across, with moderate alteration to turbid brown material, and is typically intergrown with irregular flaky aggregates of green pleochroic chlorite up to 1.5 mm wide. Some amphibole may be associated with chlorite as very fine, fibrous flakes. Minor epidote is intergrown with chlorite as granular aggregates. Subhedral magnetite crystals up to 1 mm are disseminated through the dolerite.

The basalt is extremely fine-grained at the contact and consists mainly of a highly altered turbid matrix of chlorite with intergrown opaque and semi-opaque material, which probably represents a chilled margin. The matrix has an equigranular texture and also contains poorly defined, elongated feldspar crystallites. Euhedral fresh feldspar phenocrysts up to 0.5 mm long are disseminated through the basaltic matrix.

This sample is mildly fractured and is transected by veins up to 0.2 mm wide, typically lined with granular calcite. Veins occur both in the fine-grained basalt and in the coarse-grained dolerite, but are much more evident in the basalt. Opaque to translucent iron oxides also locally occur as narrow fracture- and vein-fillings, as do localised concentrations of chlorite.

The basalt coarsens upwards from the contact. Sample 6930RS3 consists of the following constituents:

	%
Plagioclase	40
Pyroxene	20
Chlorite	20
Prehnite	5
Sericite/clay	3
Zeolite	3
Potash feldspar	3
Calcite	1
Opaques and semi-opaques	5

Plagioclase laths up to 3 mm in size form a subophitic intergrowth with anhedral pyroxene crystals, which are generally less than 0.5 mm in size and tend to be interstitial to the plagioclase laths. At least some of the pyroxene has a very weak pleochroic purple to reddish colour typical of titan-augite. A fibrous, weakly pleochroic chlorite, of grain size generally less than 0.5 mm, also forms angular interstitial fillings between the plagioclase laths. The laths exhibit well developed polysynthetic twinning and show incipient alteration to finely divided sericite. Within localised areas, the plagioclase has very low birefringence, possibly representing partial replacement by a zeolite.

The basalt is transected by veins up to 1 mm wide consisting mainly of prehnite, forming a granular to fibrous-textured mosaic. Smaller amounts of a weakly birefringent zeolite, potash feldspar and carbonate locally form granular intergrowths with the prehnite veins. The zeolite also locally forms narrow fracture linings less than 0.2 mm wide. Traces of calcite were also noted locally as fine intergrowths with plagioclase.

Opaques disseminated through the basalt as anhedral grains and aggregates up to 0.2 mm wide are not appreciably magnetic. A translucent brownish material tends to be associated with the opaques in small amounts and is most likely leucoxene or a similar titanium mineral.

Sample 6930RS1 is very similar, with randomly oriented plagioclase laths up to 1.5 mm long and interstitial pyroxene generally less than 0.8 mm. A pale green weakly pleochroic phyllosilicate interstitial to plagioclase may be serpentine. This rock is transected by 0.3 mm wide fractures, filled with a finely granular, weakly birefringent mineral, possibly a zeolite, and lined with marginal chlorite concentrations.

Sample 6930RS2 is a banded rock with greenish-grey and dull white bands, the latter containing calcite. The dark bands are basaltic and consist of intergrown pyroxene crystals up to 0.8 mm and plagioclase laths up to 1 mm long. The plagioclase is partly replaced by a weakly birefringent mineral, possibly a zeolite. Pleochroic green chlorite is also intergrown with this portion of the rock as irregular patches up to 0.5 mm wide. The pale-coloured bands are veins consisting mostly of prehnite crystals up to 3 mm long and having a radiating and weakly fibrous texture. These mainly form a coarsely granular mosaic, although finer prehnite (0.1 mm) also occurs. Calcite is intergrown with prehnite as granular aggregates up to several millimetres wide. Some calcite also forms granular veinlets transecting the prehnite. A weakly birefringent zeolite locally forms discontinuous bands and lenses up to 1 mm wide. At least some of this zeolite forms prismatic crystals up to 1 mm long, but mostly it is finer-grained and is locally granulated. A fibrous chlorite is associated with the prehnite and exhibits a well developed preferred orientation parallel to the overall banding. Opaques are disseminated through the mafic portion of the rock as anhedral grains and aggregates up to 0.2 mm wide. Most of the opaques have fine intergrowths of a weakly translucent brown material.

The basalt overlying the dolerite in the drillcore is clearly younger on the basis of contact relationships. The presence of a thin basalt vein within the dolerite suggests that the upper basalt may also be intrusive. The chilled, originally glassy, marginal phase of the basalt incorporating fragments of the dolerite is consistent with an intrusive relationship, but the possibility of the contact being the base of a basalt flow cannot be completely ruled out, though it is less likely. In either case, a significant time must have elapsed between the two crystallisation events, sufficient to allow slow cooling of the dolerite at depth. If the basalt is a flow, additional time would be required for erosion of the dolerite to its depth of crystallisation.

There is no evidence of a tectonic foliation in any of these rocks, and their partial deformation appears to be of a mainly brittle nature. The incipient alteration was at least partly deuteric and involved the formation of very low-grade minerals such as zeolite and prehnite. The lack of a severe tectonic and metamorphic overprint in these rocks suggests either that they post-date the Delamerian Orogeny, or that Delamerian effects in this region were mild enough to permit a rigid body of mafic igneous rock to remain relatively undeformed. This contrasts with the high-grade metamorphic belt that crosses the eastern Mount Lofty Ranges and is represented in parts of the Murray Basin region (e.g. migmatite northeast of Mannum).

GEOCHEMISTRY

Two basalt and two dolerite samples were submitted to Amdel for major and minor element analyses. Silicate analyses were received from Amdel (Hanckel, 1989):

	6930RS1	6930RS3	6930RS5	6930RS6	basalt
basalt	dolerite	dolerite			
SiO_2	48.4	48.2	54.3	47.1	
TiO_2	1.90	1.85	2.32	2.56	
Al_2O_3	14.2	13.7	12.3	12.5	
Fe_2O_3	11.8	12.1	12.1	15.1	
MnO	0.19	0.18	0.18	0.19	
MgO	8.40	7.90	3.98	5.55	
CaO	7.95	7.60	4.98	5.25	
Na_2O	3.08	3.28	4.14	4.60	
K_2O	0.75	1.50	2.16	0.49	
P_2O_5	0.17	0.19	0.53	0.35	
Loss on ignition	4.00	3.26	3.66	4.40	
Totals	100.84	99.76	100.65	98.09	

Minor elements (in ppm) were analysed by Classic Comlabs Ltd, using x-ray fluorescence (XRF) or atomic absorption spectroscopy (AAS):

Element		6930RS1	6930RS3	6930RS5	6930RS6
Cs	(XRF)	<10	<10	35	15
Rb	(XRF)	38	80	62	18
La	(XRF)	50	30	80	60
Y	(XRF)	32	32	68	56
Th	(XRF)	<4	4	4	4
Nb	(XRF)	4	7	18	10
Sn	(XRF)	4	<4	12	6
Zr	(XRF)	150	145	370	290
Ce	(XRF)	<20	30	50	50
Sr	(XRF)	280	240	72	100
U	(XRF)	<4	<4	<4	<4
Ba	(XRF)	155	640	125	60
Ag	(AAS)	<1	<1	<1	<1
Au	(AAS)	<2	<2	<2	<2
Cd	(AAS)	<1	<1	<1	<1
Co	(AAS)	46	40	48	34
Cr	(AAS)	34	32	4	46
Cu	(AAS)	62	60	15	28
Mn	(AAS)	810	730	930	1000
Ni	(AAS)	82	86	6	28
Zn	(AAS)	66	66	92	90
Pb	(XRF)	15	9	22	9
As	(XRF)	2	4	4	4
Bi	(ZRF)	<4	<4	<4	<4
b	(XRF)	<4	<4	<4	4
Mo	(AAS)	<2	<2	<2	<2
V	(AAS)	110	135	150	220

A number of geochemical plots were prepared in an attempt to ascertain the affinities of these mafic rocks, both in terms of tectonic environment and in relation to igneous rocks in South Australia, using these analyses and others stored on the SADME geochemical computer file.

One of the most useful plots is that relating the relatively immobile elements titanium, zirconium and yttrium (Pearce and Cann, 1973) on the basis of which tectonic settings can be identified (Fig. 2). The two dolerite samples fall into the calc-alkaline basalt field, as do some other mafic intrusives in South Australia, such as the Gairdner Dyke Swarm and the early Proterozoic amphibolites from Eyre Peninsula (A. J. Parker, pers. comm., 1989). The dolerites are similar to the Palaeozoic Kulyong Volcanics of the Officer Basin which also plot in the calc-alkaline field. The Kulyong Volcanics (Major and Teluk, 1967) occur in a cratonic basin and must have been extruded through Precambrian continental crust. The younger basalt in Nanyah 1 lies on the boundary between the intraplate basalt and ocean-floor basalt fields.

Other volcanics, including those from the Yumali area and various mafic volcanics of Proterozoic age, (e.g. Beda Volcanics of Stuart Shelf, Wooltana Volcanics of Flinders Ranges, Cadlareena Volcanics of Peake and Denison Inliers, Wantapella Volcanics of Officer Basin, and basalt in Kilroo Formation of Polda Basin; Flint et al., 1988) plot in the within-plate basalt field. These are distinct from the coarse-grained phase, though less distinct from the later basaltic phase, of rocks from Nanyah 1.

Other triangular and rectangular plots were prepared for comparison. There is a close geochemical similarity with the Palaeozoic Kulyong Volcanics, e.g. Zr/TiO_2 against Nb/Y (Fig. 3). However, possible groupings are strongly dependent on the choice of element combinations, for example in Figure 4 (TiO_2 against Zr), the Nanyah material plots closest to the volcanics of the Yumali area intersected by CSR Ltd, and also to one sample of the Early Cambrian Truro Volcanics.

A Karroo-basalt-normalised plot showing mean and standard deviations for a number of minor and trace elements in the four samples from Nanyah 1 shows little correlation with similar plots from other South Australian igneous rocks, including the Mooracoochie Volcanics of the Warburton Basin (Gatehouse, 1986), and the Kulyong Volcanics for which the triangular plots do show a similarity. Most of the trace elements, other than Ce, are lower in the Kulyong samples (Fig. 5). Insufficient data are available for the Black Hill Norite to allow meaningful comparison, but in view of the little-altered nature of the Nanyah material, a relationship to the Norite, which is post-tectonic, is possible. There is also a broad similarity to the volcanics from Yumali and the Beda Volcanics (Fig. 5).

CONCLUSIONS

Mafic rocks intersected in the Nanyah 1 drillhole include a lower coarse-grained, ophitic-textured dolerite which has been intruded by later basaltic veins and perhaps by a larger basaltic intrusion with a chilled margin. Alternatively, but less probably, the basalt could represent a flow extruded over an eroded surface of dolerite, which would require subsequent tectonic tilting. The dolerite and the basalt have undergone minor alteration to, and veining by, low-grade minerals such as zeolite and prehnite. The rocks lack penetrative deformation and may post-date the Delamerian Orogeny, or may indicate a region where its effects were comparatively mild.

The geochemistry of the mafic rocks suggests that the dolerite has calc-alkaline affinities while the basalt may reflect an extensional environment. Comparison with other igneous rocks suggests no clear-cut correlation with any known suite; a number of geochemical plots resemble those of the early Palaeozoic Kulyong Volcanics.

ACKNOWLEDGEMENTS

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FIGURES

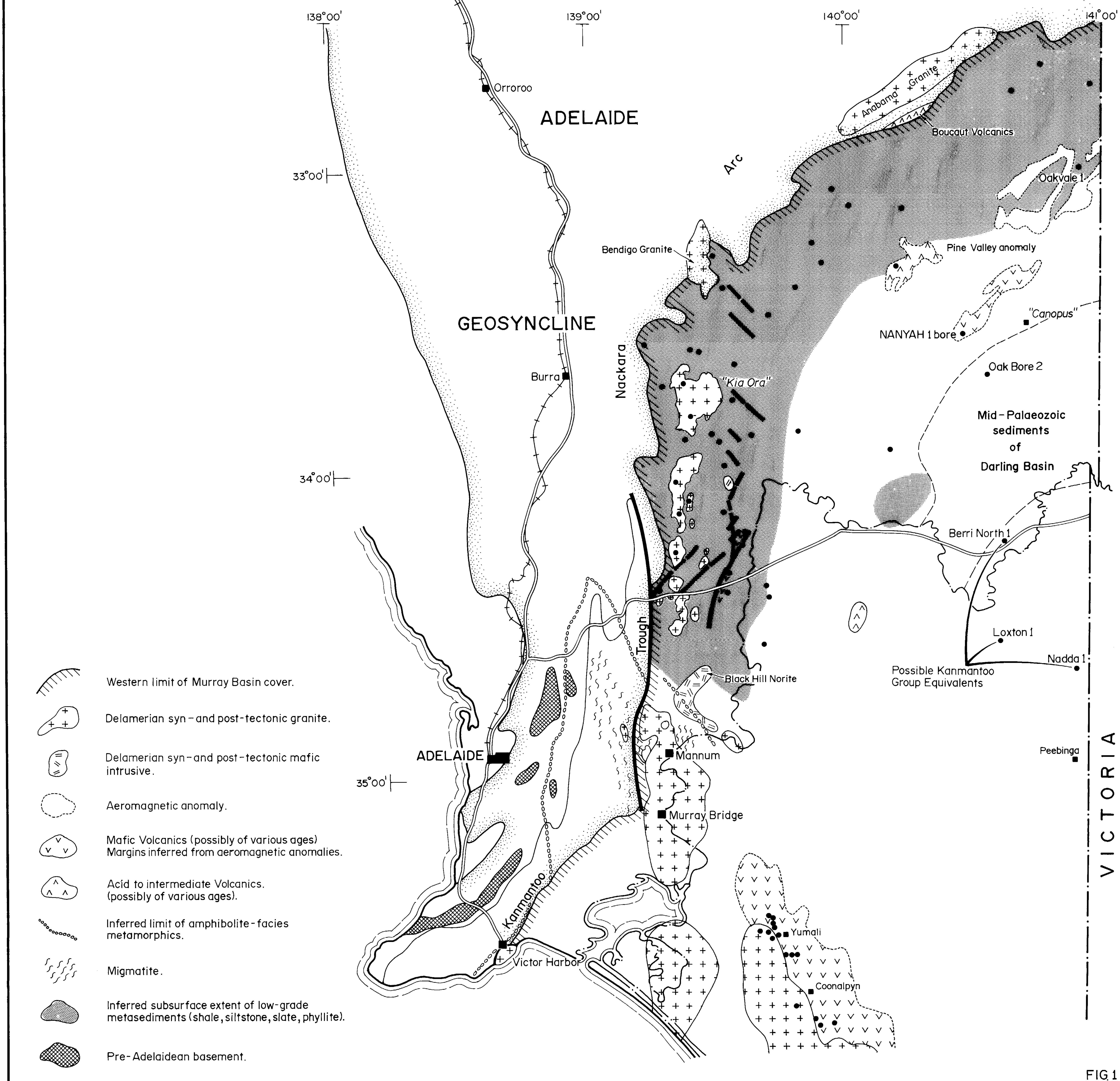
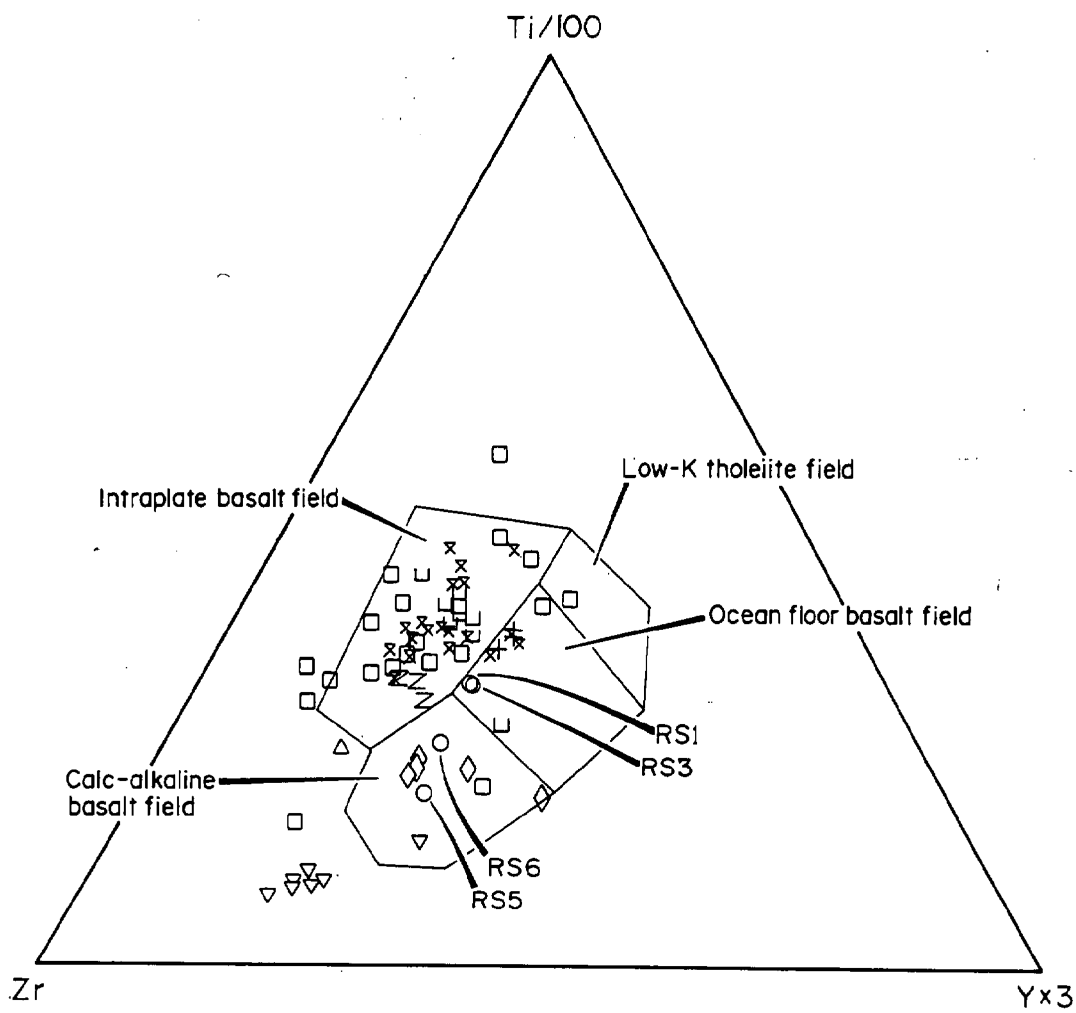


FIG. 1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED W. Preiss	C.D.O.	DATE 9.8.89
MAFIC IGNEOUS ROCKS, NANYAH 1 BOREHOLE	DRAWN J.W.	SCALE 1:1000000	
LOCATION AND GENERALISED BASEMENT GEOLOGY	DATE June '89 CHECKED	PLAN NUMBER 89-196	

4844



○ Mafic rocks from Nanyah 1.

□ Volcanics from Yumali area.

△ Truro Volcanics.

\+ Wooltana Volcanics.

× Cadlareena Volcanics.

◊ Kulyong Volcanics.

▽ Mooracoochie Volcanics.

⧖ Beda Volcanics.

Z Wantapella Volcanics.

⊔ Kilroo Formation.

FIG.2

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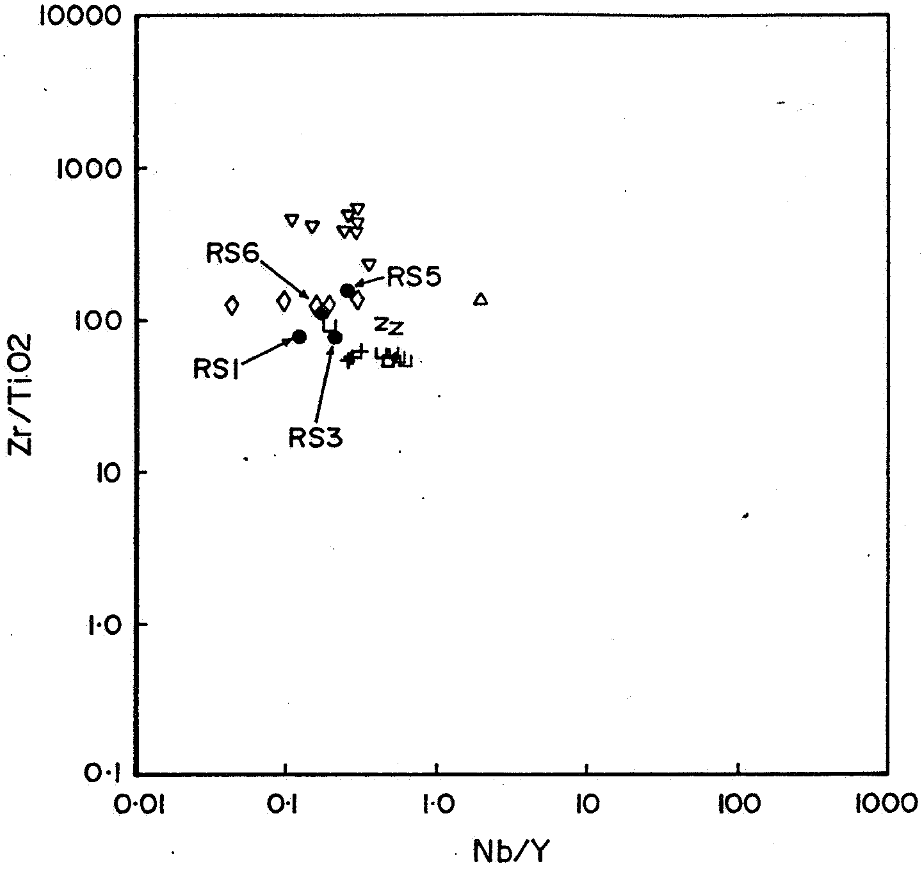
SOUTH AUSTRALIA

MAFIC IGNEOUS ROCKS, NANYAH 1 BOREHOLE

TRIANGULAR DIAGRAM Ti/100-Zr-3y

COMPILED W.Preiss	C D O	9·8·89 DATE
DRAWN J.W.	SCALE	
DATE June '89	PLAN NUMBER	
CHECKED	S20850	

4844

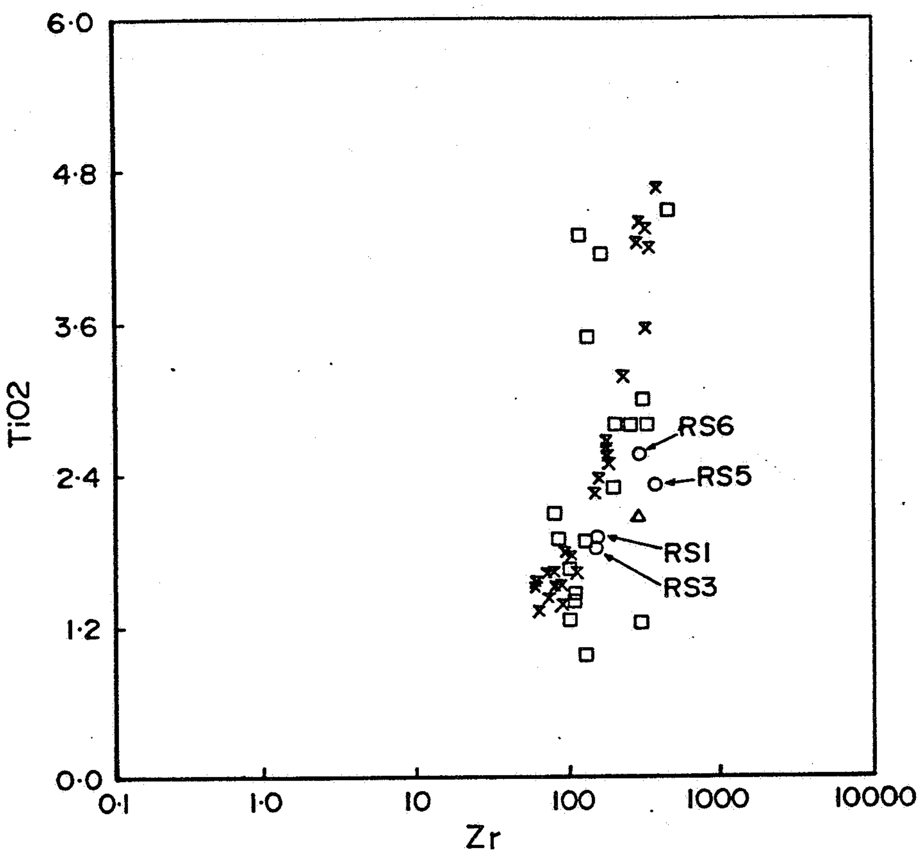


● Mafic rocks from Nanyah I.
▵ Truro Volcanics.
+ Wooltana Volcanics.
× Cadlareena Volcanics.
◊ Kulyong Volcanics.
▿ Mooracoochie Volcanics.
z Wantapella Volcanics.
u Kilroo Formation.

FIG. 3

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED W. Preiss	C.D.O.	DATE
MAFIC IGNEOUS ROCKS, NANYAH 1 BOREHOLE	DRAWN J.W.	SCALE:	
GEOCHEMICAL PLOT Zr/TiO_2 AGAINST Nb/Y	DATE June '89	PLAN NUMBER	
	CHECKED	S20851	

1844



o Mafic rocks from Nanyah 1.

□ Volcanics from Yumali area.

△ Truro Volcanics.

X Beda Volcanics.

Z Black Hill Norite.

FIG. 4

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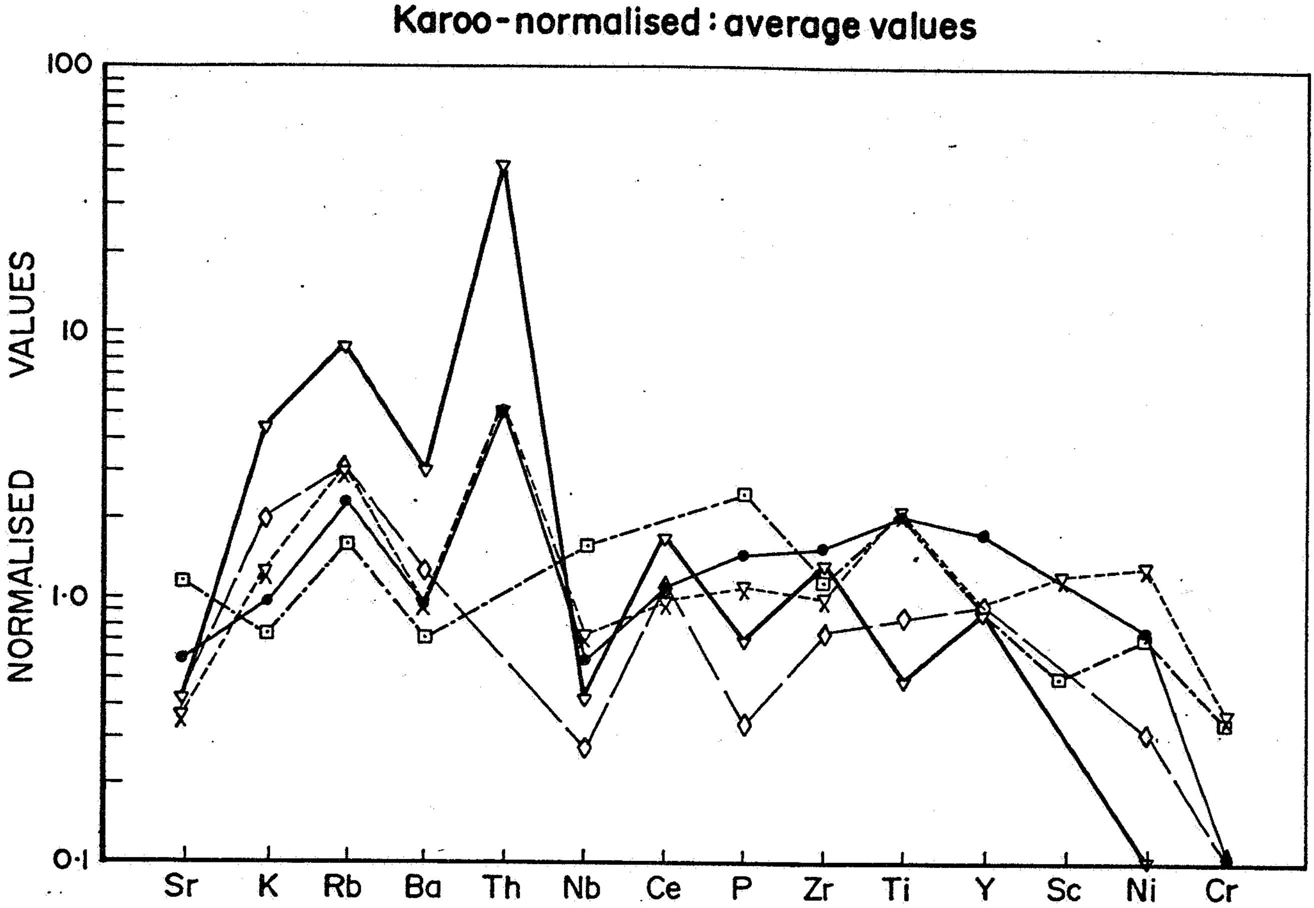
MAFIC IGNEOUS ROCKS, NANYAH 1 BOREHOLE
GEOCHEMICAL PLOT TiO_2 AGAINST Zr

COMPILED W. Preiss	C D O	DATE
DRAWN J.W.	SCALE	
DATE June '89	PLAN NUMBER	
CHECKED	S20852	

4844



● Nanyah 1.

▽ Mooracoochie Volcanics.

◊ Kulyong Volcanics.

X Beda Volcanics.

⊡ Basalts from Yumali area.

FIG.5

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED W. Preiss	CDO DATE
MAFIC IGNEOUS ROCKS, NANYAH 1 BOREHOLE	DRAWN J.W.	SCALE
KAROO NORMALISED PLOTS	DATE June '89	PLAN NUMBER
	CHECKED	S20853

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